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## The ESO Large Programme “First Stars”

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### 1 Introduction

In ESO period 65 (April-September 2000) the large programme 165.N-0276, led by Roger Cayrel, began making use of UVES at the Kueyen VLT telescope. Known within the Team and outside as “First Stars”, it was aimed at obtaining high resolution, high signal-to-noise ratio spectra in the range 320 nm – 1000 nm for a large sample of extremely metal-poor (EMP) stars identified from the HK objective prism survey [3, 4]. The goal was to use these spectra to determine accurate atmospheric parameters and chemical composition of these stars which are among the oldest objects amenable to our detailed study. Although these stars are not the first generation of stars they must be very

close descendants of the first generation. One may hope to gain insight on the nature of the progenitors from detailed information on the descendants.

The extremely metal-poor stars are very rare objects and finding them in large numbers requires specially designed surveys. All of the proponents of the large programme had been actively working on the medium-resolution follow-up of the HK survey (results still to be published), from either ESO La Silla, Kitt Peak or Roque de los Muchachos. Such a follow-up is mandatory in order to obtain a good list of candidates on which one can invest the time of an 8 m telescope.

The programme was allocated a total of 39 nights between periods 65 and 68, these were split into 8 observational runs of unequal length. The observations were carried out in visitor mode because UVES was used in non-standard settings. The settings selected were Dic1 396+573 and Dic1 396+850, typically with a 1'' slit for a resolution  $R \sim 43000$ . These settings were preferred over the standard Dic1 390+580 and Dic1 390+860, because you gain the Ba II 455.4 nm line in the blue, Zn I 471 nm in the red and Li I 670.8 nm in the reddest setting.

The main results of the large programme are published on a series of papers "First Stars" on A&A, so far 10 papers have been published, one is in press, a few more in preparation. In addition a number of papers not in the "series" have been published, up to know there are 19 refereed papers published, which make use of the data acquired in the course of this large programme.

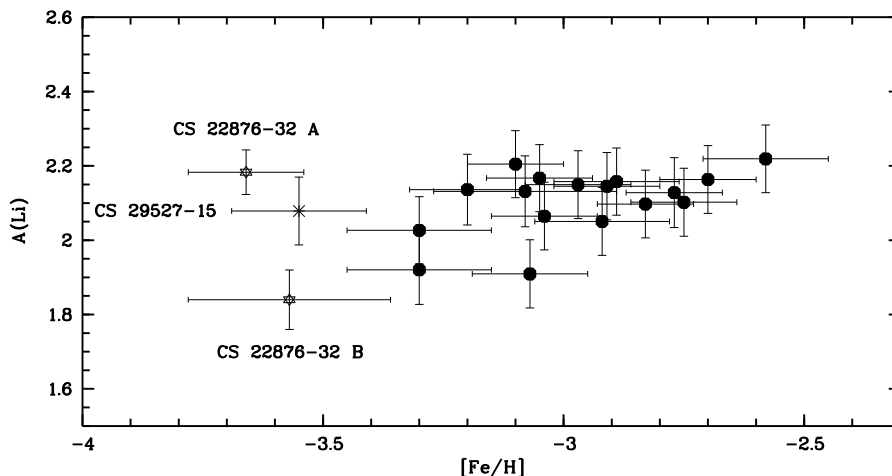
In this contribution we highlight the main results of the large programme.

## 2 Uranium in a EMP star

The first surprise came quite early in the programme, Vanessa Hill was conducting the observations in August 2000 when she realised, from the quick look data, that the giant CS 31082-001 had an exceptional spectrum, characterised by extremely low metallicity and a large enhancement of the r-process elements. She was in fact able to identify immediately the Th II 401.9 nm line, which displayed a remarkable strength. This induced her in the following nights to acquire blue spectra of higher resolution with slicer # 2 in the hope of being able to identify and perhaps measure uranium in this star. The star is now often colloquially dubbed as "Hill's star", and in fact her intuition proved correct since this was the first metal-poor star for which it was possible to measure the uranium abundance, opening up a new possibility for nucleochronology [6, 12]. This star actually showed how little we knew on the r-process. While Th/U proved to be a reliable chronometer Eu/Th and Eu/U provided unrealistically small ages, using the then available production ratios. Also Pb in this star is a real puzzle, in fact the majority of lead in this star is what you expect from the decay of Th and U, leaving very little space for Pb production during the r-process [13].

### 3 The Spite plateau at the lowest metallicities

Ever since Monique and François Spite discovered that warm metal-poor stars share the same Li abundance (the *Spite plateau*) [17, 18], there has been an active research on this field. What we wish to understand is if this *plateau* indicates the primordial Li abundance, as initially proposed [17, 18], or not.



**Fig. 1.** The Spite plateau at the lowest metallicities as portrayed by the “First Stars” data. The stars whose names are labelled are binaries, for CS 22876-32 an orbital solution is available and the analysis has been done taking properly into account the veiling and Li in both components has been measured, for CS22957-15 this has not been possible, due to the lack of the necessary data, however the correction for the veiling is likely not very large.

The “First Stars” large programme allowed to explore the *Spite plateau* at the lowest known metallicities. There are no known dwarf stars with a metallicity (meant as  $Z$ , total metallicity, not  $[\text{Fe}/\text{H}]$ ) lower than the stars shown in Fig.1. The data are those of [5] and [11], the picture which emerges is that the plateau seems to continue at the lowest metallicities. It is possible that there is a larger scatter, however the impact on this picture of stars in which lithium may have been partially depleted is yet unclear. The difference in lithium content between the two components of the binary system CS 22876-32 has no clear explanation. The cooler component (star B) has an effective temperature of 5900 K and should not display Li depletion according to standard models.

From the cosmological point of view there is a tension between the value of the *Spite plateau*,  $A(\text{Li}) \sim 2.1$  and the value predicted by standard big bang nucleosynthesis, when the baryonic density derived from the power spectrum of the fluctuations of the cosmic microwave background is used [16, 5],

$A(\text{Li}) = 2.64$ . Several ways to explain this discrepancy have been suggested, and generally they go in two possible directions: a) the *Spite plateau* does not represent the primordial abundance or b) primordial nucleosynthesis did not proceed as assumed in the “standard” model. At present both solutions are possible and further observations of EMP stars, to understand if there is an excess scatter of Li at the lowest metallicities, could give useful indications.

## 4 Abundance ratios, what did we learn ?

When we started the large programme, several of us, were expecting that at the lowest metallicities we would begin to see the effects of the pollution of very few supernovae (SNe), possibly a single supernova. As a consequence we were expecting considerable scatter in the abundance ratios, which would be the signature of the different masses of the polluting SNe and incomplete mixing of the gas in the early Galaxy. To the surprise of several of us we found instead that the majority of elements C to Zn display a remarkable uniformity, with well defined trends with metallicity [7]. The scatter in these trends can be totally explained by observational error. One explanation of this low scatter is an efficient mixing of the early Galaxy. Alternatively one could argue in favour of a narrow range of masses of SNe actually contributing to chemical enrichment.

The exceptions, among lighter elements, were Na and Al, that displayed a star to star scatter larger than observed for other elements. This excess scatter also made the definition of trends somewhat ambiguous. A reanalysis of both elements using full NLTE line formation was in fact able to solve the problem [1, 2]. Sodium appears to be constant with metallicity among EMP stars, with  $[\text{Na}/\text{Fe}] = 0.21 \pm 0.13$ , and the same is true for aluminium with  $[\text{Al}/\text{Fe}] = 0.08 \pm 0.12$ .

The observations of C and N, showed that in a  $[\text{C}/\text{Fe}]$  vs.  $[\text{N}/\text{Fe}]$  diagram the giants split nicely into two groups, one with high  $[\text{N}/\text{Fe}]$  and low  $[\text{C}/\text{Fe}]$ , which we call “mixed”, the other with lower  $[\text{N}/\text{Fe}]$  and higher  $[\text{C}/\text{Fe}]$  which we call “unmixed” [19, 20]. As expected from the theory of stellar evolution “mixed” stars are typically the more luminous giants, although there are a few exceptions.

At variance with lighter elements the n-capture elements display a large scatter, which cannot be explained by observational errors [10]. Such scatter, coupled with the very uniform ratios of the lighter elements demands an inhomogeneous chemical evolution. Already from the results of CS 31082-001 it was clear that the r-process is not “universal” and several r-processes may be needed. The data on n-capture elements clearly indicates that a *second* r-process is the main production channel at  $[\text{Ba}/\text{H}] < -2.5$ .

Among the dwarf stars we found four which were C enhanced [15, 14]. In all of them the C-enhancement has come about as a consequence of mass-transfer from an AGB companion. The abundance pattern of n-capture elements is

rather diverse among the stars, suggesting nucleosynthesis taking place under different physical conditions.

The giant CS 22949-037 is one of the most extraordinary found in the course of the large programme[8]. With  $[\text{Fe}/\text{H}] \sim -4.0$  it is one of the most iron poor stars found in the sample, however its high abundances of CNO ( $[\text{O}/\text{Fe}] \sim +2$ ,  $[\text{C}/\text{Fe}] \sim +1.2$ ,  $[\text{N}/\text{Fe}] \sim +2.6$ ) make its global metallicity  $Z$  not so extreme as that of the four giants with  $[\text{Fe}/\text{H}] \sim -4$ [9], which are, so far, the star with the lowest  $Z$  known. There is no totally satisfactory model to explain the abundance pattern in CS 22949-037, however it is clear that some special kind of SN is needed to explain such an extraordinary pattern.

## 5 Needs for the future

One would like to extend the work done so far, with high resolution, high S/N ratio spectra of stars of even lower metallicities. Such stars should be found by on-going and projected surveys (SEGUE, LAMOST, SkyMapper...). Most of these are however expected to be around 18th magnitude or fainter, UVES can work at these faint magnitudes, but...slowly. The proposed high resolution spectrograph ESPRESSO (see Pasquini this meeting) in the mode combining the 4UTs, would be ideal for these targets. According to the preliminary estimates ESPRESSO 4UTs, at a resolution of  $R \sim 45000$  should beat UVES in efficiency for all targets fainter than  $V=17.5$ , when read-out-noise begins to be important.

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